4. CONTAMINANT FATE AND TRANSPORT MODELING

4.1 OU 3-14 Conceptual Model

The conceptual model is a statement of understanding of past and present site conditions, and it illustrates the physiochemical factors that control the movement of groundwater and associated contaminants in the subsurface. It is a representation against which observations can be compared. The conceptual model represents what is known about the physical setting and the subsurface hydrogeology, interaction of contaminants with the surrounding water and rock, and movement of contaminants from the source to groundwater. The conceptual model is the basis for the numerical model and for developing a list of data gaps resulting in DQOs, which are the basis for future data collection and use.

4.1.1 Physical Setting

INTEC is situated within the boundaries of the INEEL on the Snake River Plain. The elevation of INTEC is approximately 4,917 ft above mean sea level and it receives an average of 8.7 in. of precipitation per year. Average snowfall per year is 27.6 in. Snow tends to accumulate over the winter months and is removed from areas such as roadways, sidewalks, and parking lots and placed in inactive areas until it melts in the spring. A detailed investigation of water infiltration rates was conducted at the Central Facilities Area Landfill by Miller, Hammel, and Hall (1990). Based on soil analysis, precipitation, and evaporation estimates, a range of infiltration rates from 1 to 1.6 in./yr was reported. The infiltration rate at INTEC may be lower in some areas due to impervious ground and drainage ditches and higher in others due to run-off infiltration areas that are fed by drainage from impervious surfaces.

By design, INTEC was constructed on relatively thick, gravely, medium-to-coarse alluvial deposits that allowed the burial of various utility lines, storage tanks, and other process-support infrastructure. The alluvium ranges in thickness from 25 to 60 ft and rests on top of basalt flows that form a topographic basin in the area directly south of the tank farm. The surficial alluvium is underlain by a series of basalt flows and continuous-to-discontinuous sedimentary interbeds. Water that infiltrates downward through the alluvium and underlying transmissive basalts encounters zones of low-permeability interbed material or low-permeability basalt flows, creating local areas of high-moisture content or saturation. If enough recharge water is present, perched water bodies form and exist as long as a source of recharge water is present.

Excavation of the alluvium to the surface of the basalt and backfilling associated with the construction of the subterranean tanks at INTEC likely resulted in areas of higher permeability. If a zone of low-permeable silt and clay was encountered during excavating, it was likely backfilled with the more permeable coarse alluvial material. This disturbed zone around the tank farm may have originally had an increased infiltration rate for liquids moving through the surficial sediments. However, a 30-mil-thick Dupont Polyolefin 3110 membrane discussed in Section 2.2 was installed over the surface of the tank farm in 1977 and has likely decreased infiltration significantly.

The topographic depression (discussed in Section 4.1.3.3) in the top of the basalt located south and southwest of the tank farm area could act as a basin, collecting water infiltrating through the alluvium and directing that water toward the depression, provided the basalt immediately beneath the surficial alluvium is relatively impermeable. If this basin feature is controlling the movement of groundwater in the subsurface, infiltration rates south of the tank farm area would increase and subsequently have significant effects on the distribution of water in the perched systems below.

4.1.2 Subsurface Geology of INTEC

The USGS and the DOE have drilled and sampled the INTEC subsurface extensively in an effort to understand and monitor the movement of groundwater and contaminants beneath INTEC. The geologic data acquired during well drilling at INTEC were used to interpret the INTEC subsurface.

To date, a total of 121 wells have been drilled at and around INTEC. Forty-seven of these wells were drilled to depths that penetrate into the SRPA (36 USGS monitoring wells, four production wells, and seven INTEC monitoring wells); 73 of the wells are completed in the vadose zone to monitor the various perched water bodies beneath INTEC; and numerous holes have been drilled at INTEC in the surficial sediments to the top of the basalt. Two of the existing deep aquifer wells and 11 of the shallow perched wells were cored during their installation. The well totals discussed above include the ICDF wells that were completed south of INTEC during October 2002. Five SRPA wells and six perched water wells with up to three completion intervals were installed to monitor groundwater around the ICDF.

A detailed study of borehole data from the INTEC wells was completed during the preparation of the OU 3-13, Group 4 Monitoring Well and Tracer Study Report (DOE-ID 2003a). The study included the evaluation of available basalt/interbed core; geochemical, paleomagnetic, and K-Ar age date; and petrographic data. Results of the study indicated that several distinct units exist beneath INTEC that can be used as marker units. The marker units included the following:

- Surficial alluvium—exists across the INTEC facility with the contact at the first basalt easily identified.

- Upper basalt flows—the number of basalt flows between 30 and 115 ft bgs ranges from one to four flow units. Up to four units exist beneath the northern portion of INTEC, and a single flow unit exists beneath the southern portion of INTEC. Paleomagnetic data for one of the flows at 100 to 115 ft bgs showed significantly higher inclinations than others in the group, which could potentially be used to better map the flow as new data become available.

- 110-ft interbed—generally encountered between 100 to 120 ft bgs and ranges from 3 to 25 ft thick. This interbed is an important marker unit due to its presence in nearly all of the wells that penetrate deep enough to encounter the unit. The thickest portions of the unit rest under the northeast corner of INTEC.

- High K_2O basalt flow—characterized by a high natural gamma count due to higher potassium content. The flow is found between 110 and 150 ft bgs and is absent from the east and southeast extremes of INTEC. When the flow is encountered, it lies stratigraphically below the 110-ft interbed.

- 140-ft interbed—typically encountered between 140 and 150 ft bgs. This interbed does not appear to be as continuous as the 110-ft interbed, which may be due in part to a lack of data.

- Middle massive basalt—one of the thickest, most massive basalt flows found in the vadose zone beneath INTEC. Typical thickness for this unit is around 100 ft. The base of the unit appears to be relatively flat-lying, while the upper surface has a south to southwest slope. This unit is encountered between 220 and 280 ft bgs.

- 380-ft interbed—a relatively continuous flat-lying layer that varies in thickness from 6 to 27 ft. Depth to the interbed ranges from 320 to 420 ft bgs. This interbed appears to be continuous and relatively thick beneath the INTEC tank farm and thins to the south.

- Low K_2O basalt flow—identified in wells USGS-121 and -123 and was found to have a low percentage by weight K_2O, based on geochemical sampling results. The basalt flow was found at 415 ft bgs in both wells. A similar reading from basalt was found at 384 ft bgs in well ICPP-COR-A-023.

4.1.3 Hydrogeological Setting

Water movement from the tank farm to the SRPA is impeded by less permeable geological features such as dense basalt and interbeds. A number of sources, both natural and artificial, provide water to the subsurface. This water can form perched water bodies and mobilize contaminants. At INTEC, perched water has historically formed two distinct, discontinuous zones—the northern perched water and southern perched water systems.

4.1.3.1 Sources of Perched Water. Perched water bodies exist at various depths within the 450-ft-thick vadose zone beneath INTEC. Several water sources may contribute to moisture movement and development of these perched water bodies. Human-made surface water features in the vicinity of INTEC consist of (1) two former percolation ponds that were used to dispose of water from the service waste system and (2) existing sewage treatment lagoons used to dispose of treated water. In addition, several landscaped areas at INTEC have typically been watered during the summer months, and a network of ditches is used to channel run-off from INTEC after precipitation events. Historically, a portion of precipitation run-off has been channeled to an old gravel pit (CPP-37-1) located in the northeastern portion of the INTEC, near well 37-4.

A major source of recharge has been the two former percolation ponds at INTEC (see lower center portion of Figure 4-1). An average of 1.16 million gal of wastewater was discharged to these percolation ponds each day. Discharges to these ponds ended in August 2002, when the water was diverted to a set of new percolations ponds located approximately 2 mi west of the INTEC facility. A second potential recharge source is the Big Lost River when it flows. The Big Lost River may flow all year or cease to flow entirely for several months or years, depending on the snowpack and precipitation that occurs in a particular year. Combined, these two sources were believed to supply about 90% of the recharge (DOE-ID 1997a, Appendix F). However, the contribution of recharge from the Big Lost River to perched water beneath INTEC is unclear and not well quantified. The sewage treatment lagoons (upper right, Figure 4-1), operational activities, and precipitation account for the remaining recharge. Average annual discharge to the sewage treatment lagoons is 13.9 million gal/yr. As a part of operational losses, steam condensate drains at various locations across INTEC contribute over 1.67 million gal per year to the subsurface. Although the volume of steam condensate is significantly less than the other sources, the drain locations may play an important part in recharging the northern shallow perched water zones. Other operational losses of water supply are variable and not well quantified. These are currently being identified.

4.1.3.2 Perched Water Systems. Perched water beneath INTEC is addressed under OU 3-13 Group 4; however, perched water is recognized as an integral part of the contaminant transport pathway from the tank farm soils to the SRPA and is, therefore, discussed in this section. Phase 1 of the Monitoring System and Installation Plan (DOE-ID 2000c) determined that two predominant perched water systems exist beneath INTEC, as is discussed in the Monitoring Well and Tracer Study Report (DOE-ID 2003a). A diagram of the conceptualized perched water system is presented in Figure 3-46. Other perched systems may exist across the INTEC site as isolated bodies of water caused by a localized source of recharge, such as the intermittent shallow perched water observed near the CPP-603 basins. During past INTEC operations, two distinct perched water systems (northern and southern) were created, the northern perched system being the focus of this model (Figure 4-2). A north-south fence diagram of the subsurface of the INTEC is presented in Figure 4-3.

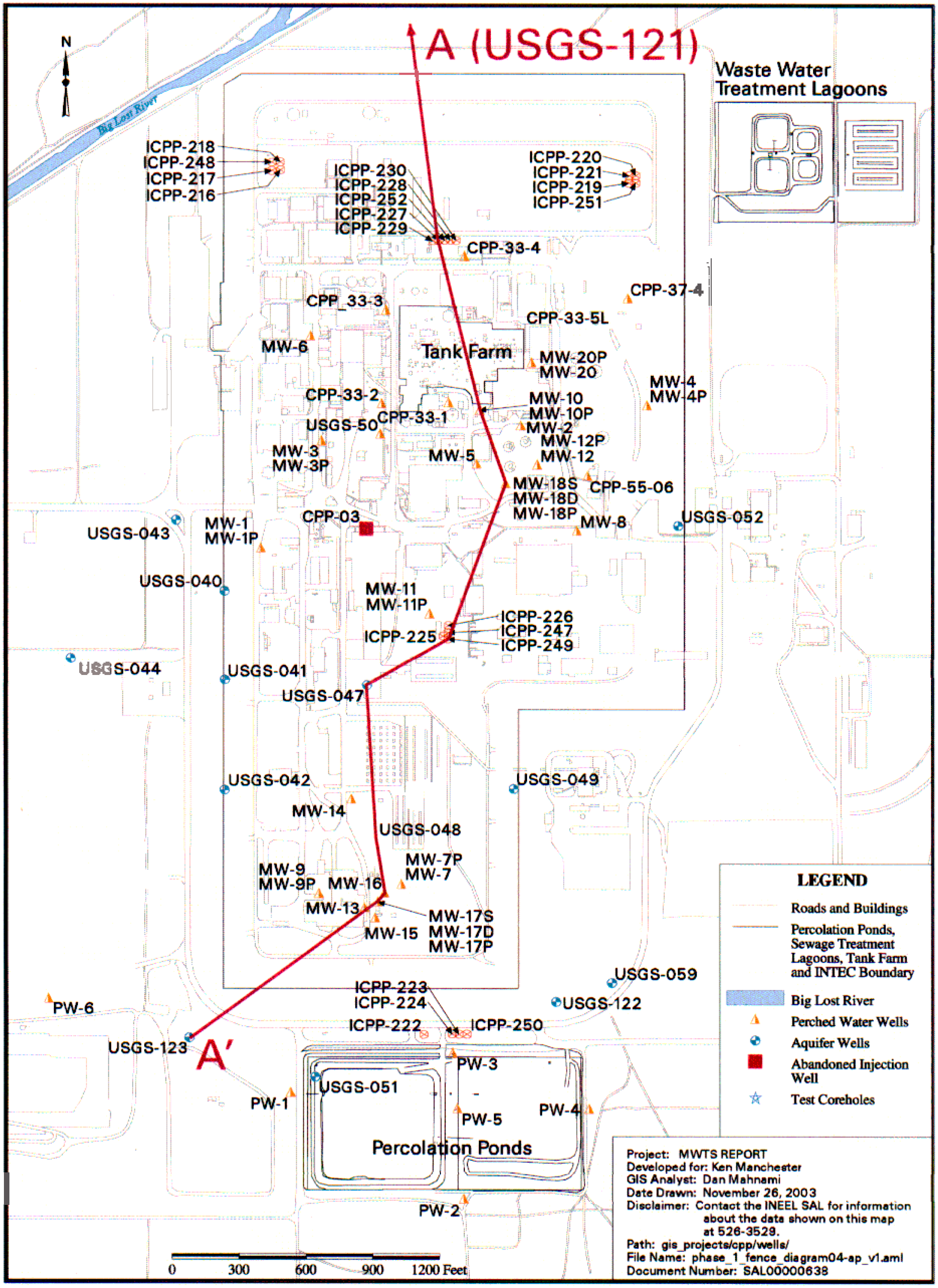

Figure 4-1. INTEC well location map.

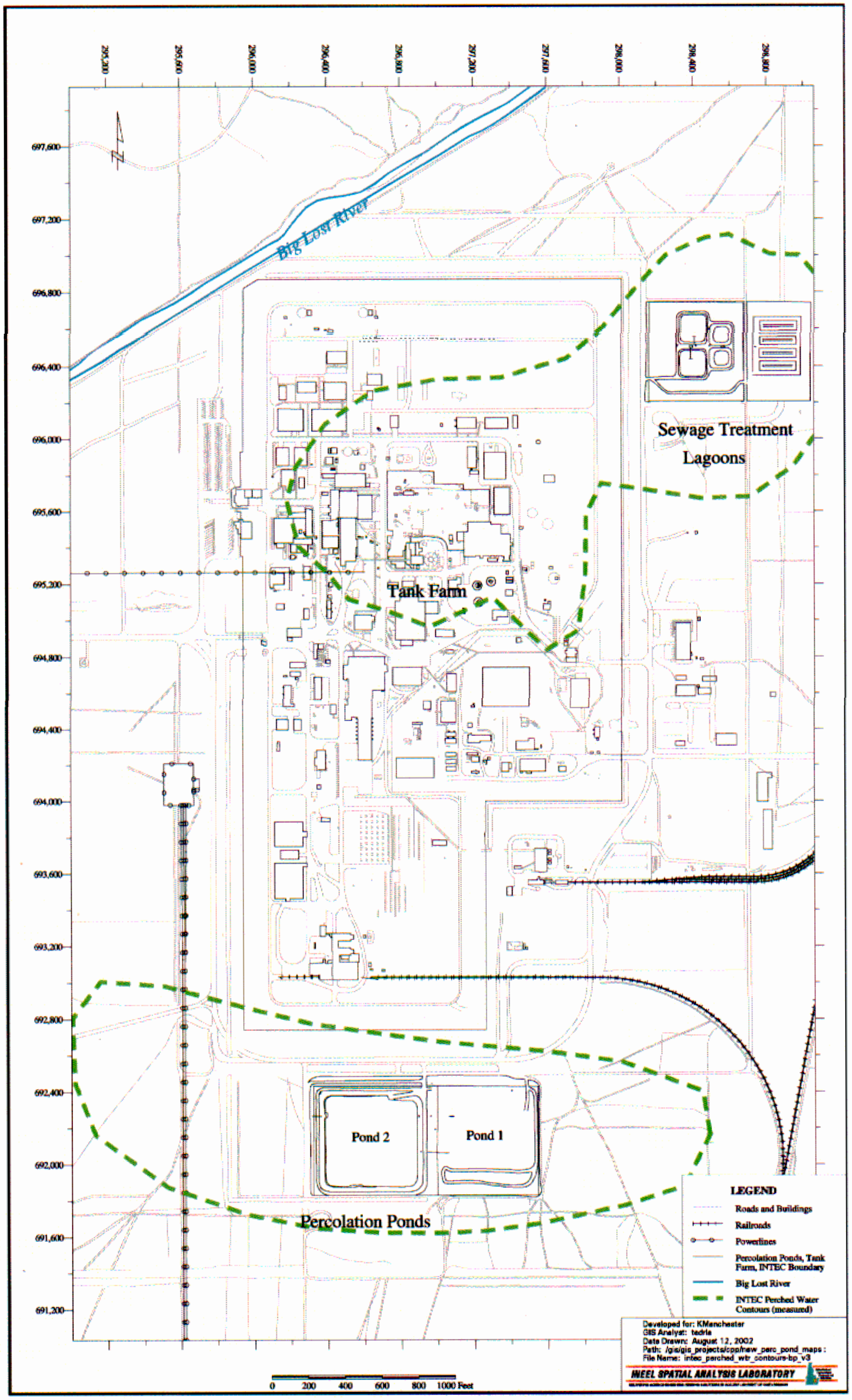

Figure 4-2. Approximate past extent of shallow perched water identified in the WAG 3 RI/FS.

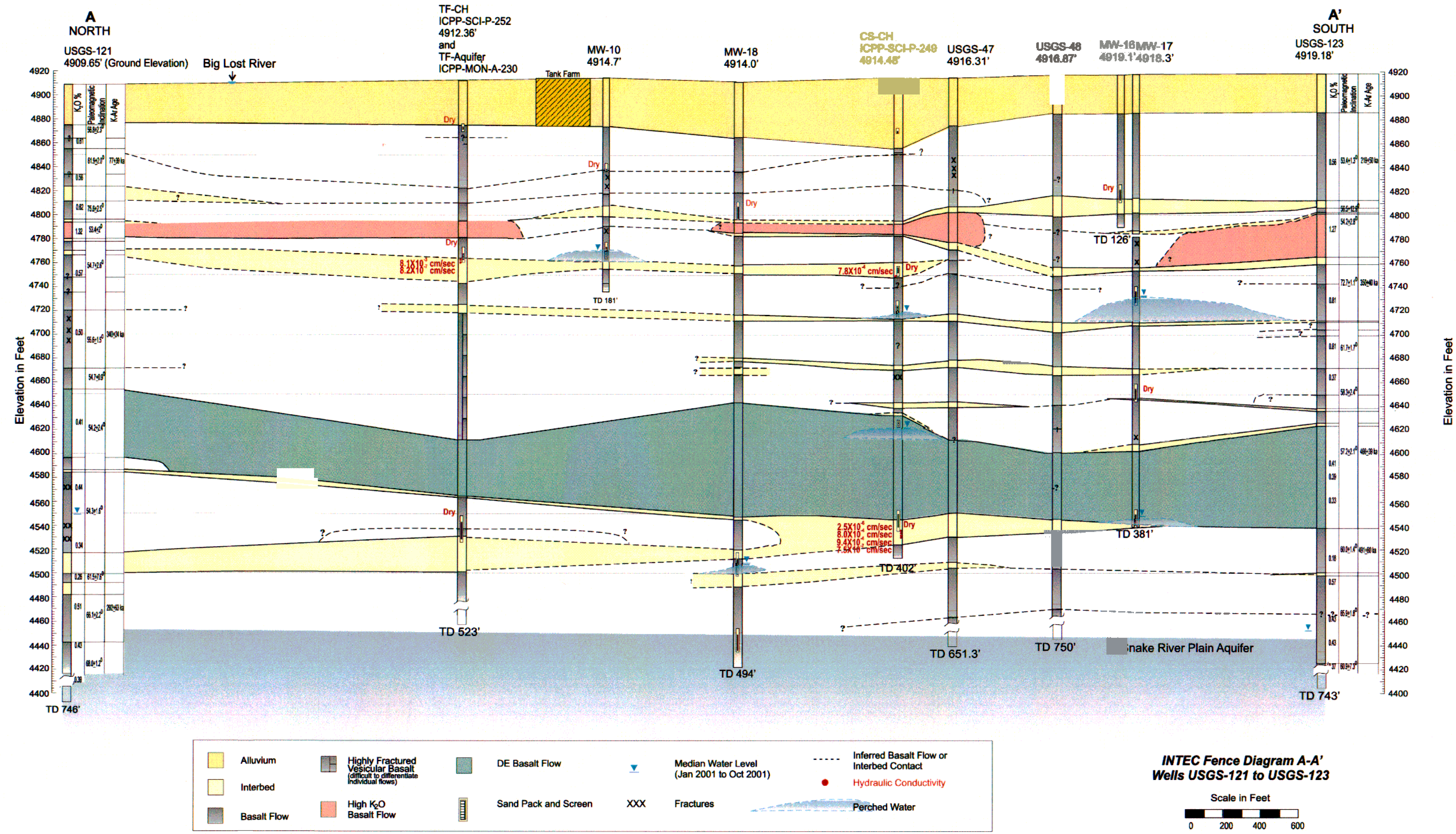

Figure 4-3. North-south fence diagram of INTEC (DOE-ID 2 a).

4.1.3.3 Southern Perched Water System. The southern perched water system was created when disposal of service wastewater began at the former percolation ponds in 1984. With a continuous source of water, the southern perched water system began to form. Water infiltrating downward through the base of the disposal ponds and coarse surficial alluvium subsequently formed perched water on the deeper sedimentary interbeds and impermeable portions of basalt flows in its movement toward the SRPA. Service wastewater was diverted from the percolation ponds in August 2002, and the southern perched water system has mostly drained out. A detailed discussion of the southern perched water system is presented in the Monitoring Well and Tracer Study Report (DOE-ID 2003a). No further discussion of this perched water system is presented in this conceptual model.

4.1.3.4 Northern Perched Water System. The northern perched water system underlies the tank farm and may affect contaminant transport from the tank farm soils to the SRPA. However, the significance of this perched water system as a pathway to the SRPA is uncertain. The 1997 extent of the northern perched water system is shown in Figure 4-2. The northern perched water system is more complex than the southern perched water system in that recharge sources are not as apparent. The most significant source of recharge comes from the sewage treatment lagoons. Geochemical data suggest numerous waters may combine to create the northern perched water system. Recharge from the Big Lost River is not well understood at this time, but analysis of data on monitoring well water levels versus river flow has not definitively established a link between the northern perched water system and river recharge. Additional monitoring has been implemented and a water balance study has been conducted as a part of OU 3-13, Group 4 activities to better understand this surface water/perched water connection (DOE-ID 2003c).

Water traveling through the surficial alluvium from any of the sources may perch on the alluvium/bedrock contact and begin to spread laterally if enough water is available. Based on limited monitoring of this potential perching mechanism, perched water does not appear to accumulate in significant quantities. However, when the Big Lost River flows, this shallow potential perching horizon may play a significant part in moving the rapidly infiltrating water laterally from the Big Lost River channel to the northern perched water area. The alluvium/basalt contact slopes to the southeast from the Big Lost River channel toward a depression in the central part of INTEC (Figure 4-4).

Water making its way past the alluvium/basalt contact continues down vertically with minor lateral spreading until this water encounters the 110-ft interbed, where vertical travel is impeded. The northern shallow perched water system then moves laterally and downward to create discontinuous perched zones associated with the 110- and 140-ft interbeds and neighboring basalt flows (Figures 4-5 through 4-7). Radiological contamination in the perched water is typically higher above the 110-ft interbed and lower in the perched zone associated with the 140-ft interbed. A significant fraction of perched water on the east side of the tank farm is believed to be originating from precipitation infiltration and/or from leaking process pipes, based on high nitrate levels, ratios of common cations and anions, and radiological contamination. The shallow perched water on the west side of the tank farm has lower nitrate concentrations, suggesting dilution of the perched water from a source having lower nitrate concentrations. One such source may be the lawn irrigation that takes place seasonally near MW-6 (Figure 4-1). Shallow perched water in the vicinity of the sewage treatment lagoons generally has higher chloride concentrations than the shallow perched water found in the tank farm area. Nitrate concentrations are elevated but not as elevated as some of the shallow perched water near the tank farm.

The extent of the northern shallow perched water remains limited mainly to areas around the tank farm and sewage treatment lagoons. The shallow perched water in this area is discontinuous and may be intermittent, depending on the regularity and output of the different recharge sources. Shallow perched water is not observed in the TF-SP well completed from 145 to 150 ft bgs northwest of well 33-4, which

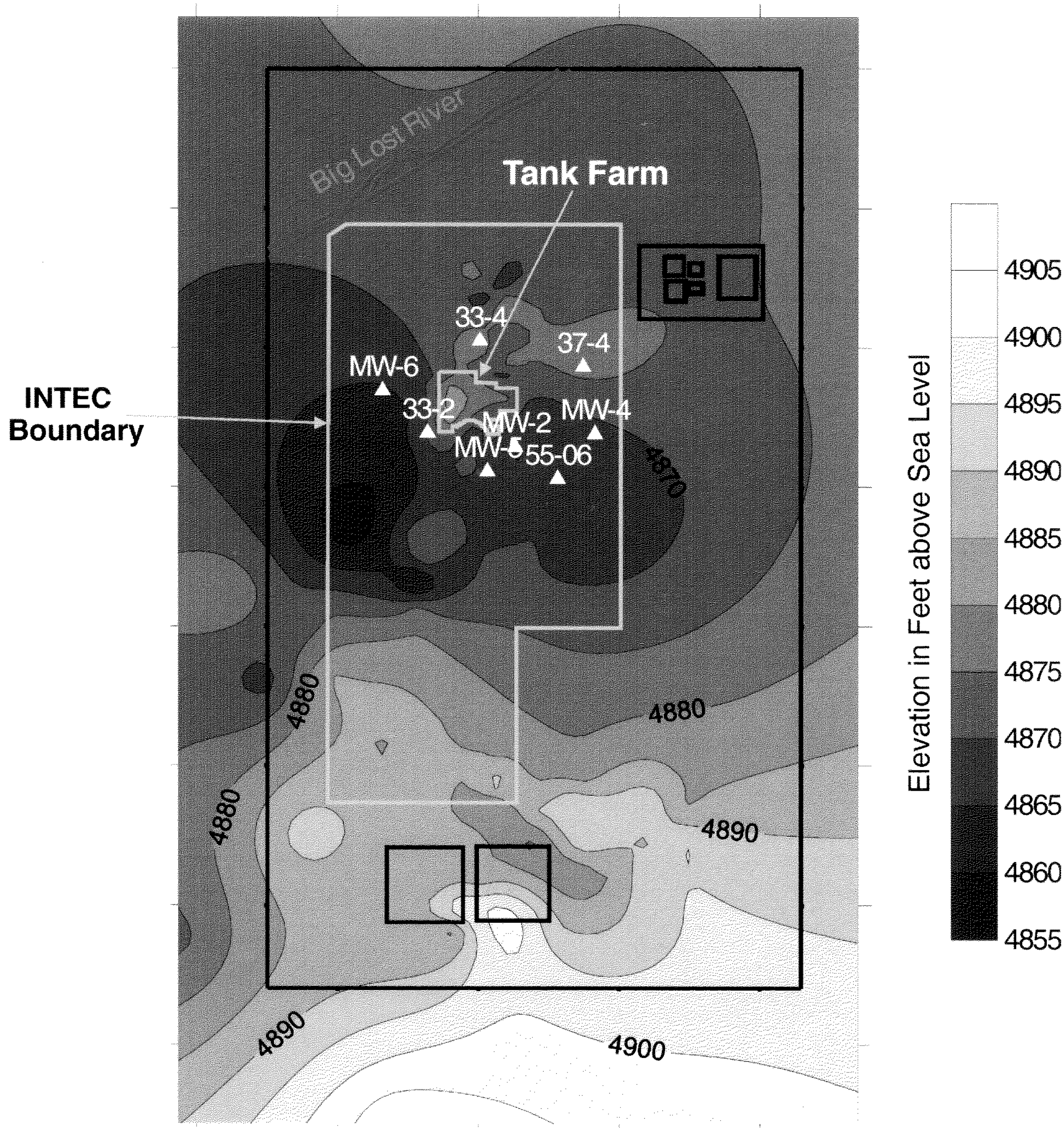

Figure 4-4. Contour map of the top surface of the upper basalt flow.

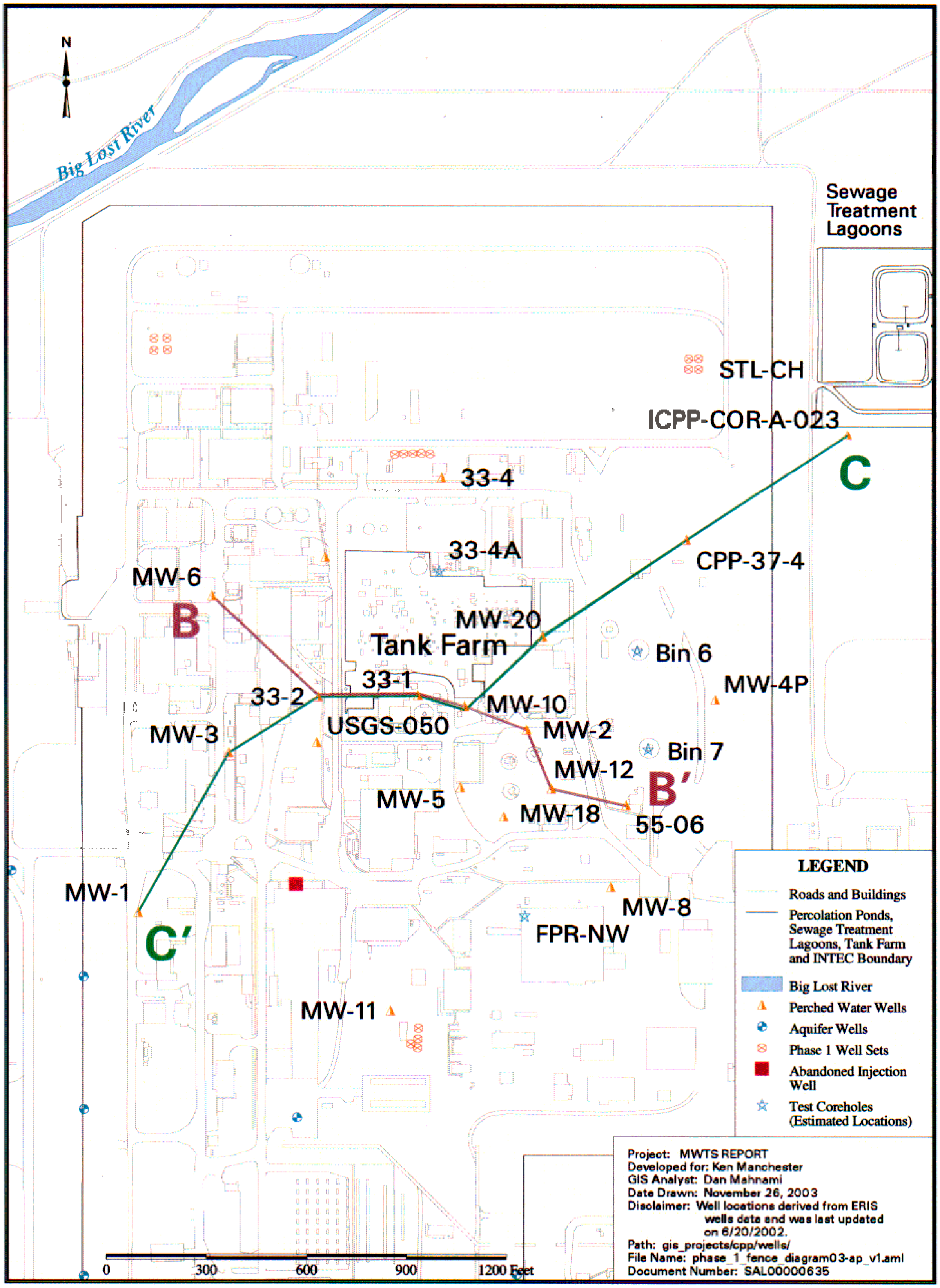

Figure 4-5. Fence diagram location map.

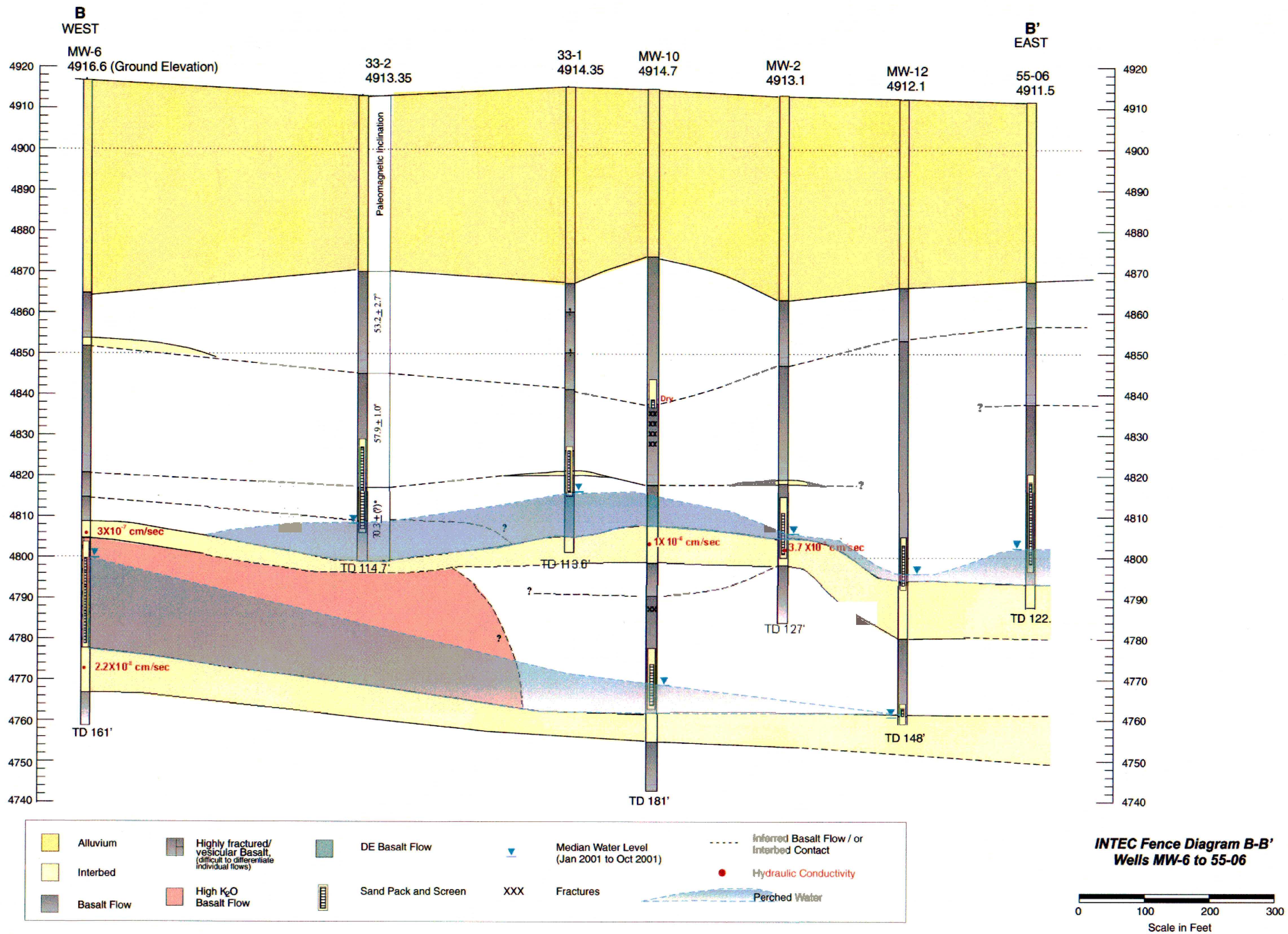

Figure 4-6. East-west fence diagram of INTEC (DOE-ID 2003a).

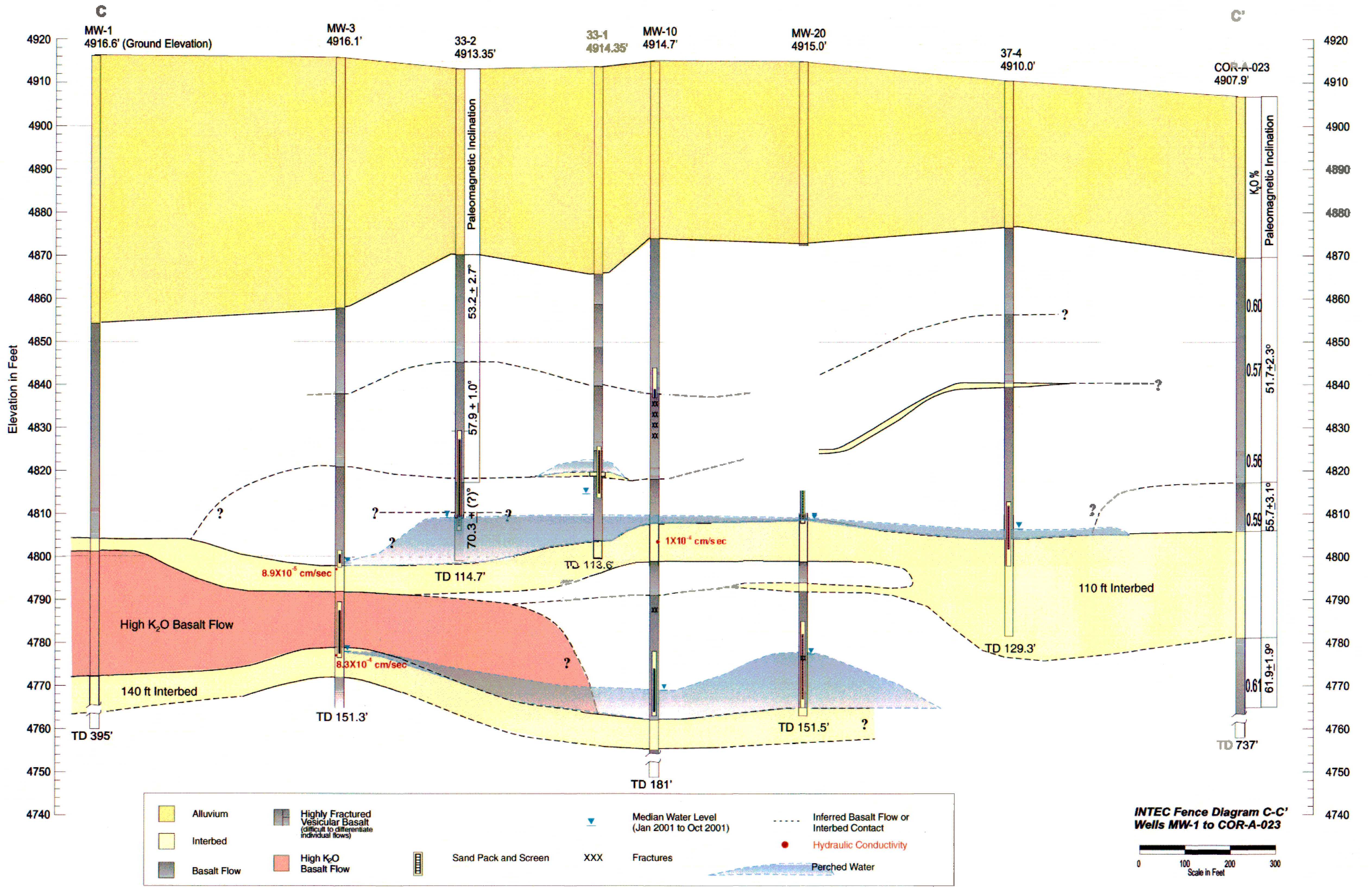

Figure 4-7. Southwest-to-northeast fence diagram through the tank farm area (DOE-ID 2003a).

generally has perched water. To the east, the shallow perched water periodically extends to MW-4, where perched water is intermittent. Based on the intermittent presence of water in MW-8, the shallow perched zone develops to the southeast area around MW-8 at various times. To the west, the shallow perched zone extends past MW-6, but the lack of shallow monitoring wells farther to the west precludes determining the western extent of the water body. To the south, the shallow perched zone is intermittent, based on dry conditions in MW-18-2 (completed from 105 to 115 ft bgs), saturated conditions in MW-11-2 (completed from 131 to 136 ft bgs), and saturated conditions detected in the tensiometer CS-SP-1 at 122 ft bgs.

Once the shallow perched water passes through the 110- to 140-ft interval, the water travels downward through several basalt flows and minor interbeds until it encounters the 380-ft interbed interval that tends to form the deep perched water zone. Small, discontinuous perched water bodies may exist between the 140-ft interbed and the 380-ft interbed due to lower permeability zones encountered by the water. Some evidence of this is provided by observed perched water in the central well set, where perched water was measured at 189 and 295 ft bgs.

The northern deep perched water originates from several sources, based on geochemical and isotope data. Water from well BLR-DP (completed from 375 to 385 ft bgs) appears to be a mixture of predominantly SRPA water with precipitation and/or Big Lost River water. The high nitrate concentrations in wells MW-1-4 and USGS-50 suggest that the water in these wells originates from the east side of the tank farm; however, the stable isotope data from USGS-50 and MW-1-6 are similar to SRPA water and do not show the higher δD and $\delta^{18}O$ values from wells on the eastern side of the tank farm.

Northern deep perched water was found in wells MW-1-4, USGS-50, BLR-DP, MW-18-1, and STL-DP. The well at STL-DP was completed from 429 to 439 ft bgs, which is considerably deeper than the other four wells and places the bottom of the well approximately 10 to 15 ft above the top of the SRPA. Deep perched water was not observed in the deep perched wells installed at the tank farm well set or the central set. Based on this limited data set, estimating the extent and continuity of the deep perched water body is difficult.

The highest levels of radioactive contamination in the perched water occurs beneath the northern portion of INTEC, particularly associated with MW-2, MW-5, and 55-06. The maximum gross alpha and gross beta activities measured in the upper shallow perched water at MW-2 were 4,700 ± 200 and 925,000 ± 1,000 pCi/L, respectively. At a depth of approximately 140 ft in the lower shallow perched water, the maximum gross alpha and gross beta concentrations measured in the perched water at MW-10 were 711 ± 87 and 48,800 ± 100 pCi/L, respectively, and at MW-20 were 137 ± 9 and 65,300 ± 600 pCi/L, respectively.

The most significant radionuclides in the upper shallow perched water body are Sr-90 and Tc-99. Low levels of tritium were also detected in the same zone. The low tritium concentrations in the upper shallow perched water zone are a significant contrast to the waste stream that was directed to the INTEC injection well (site CPP-23), where the vast majority of the associated radioactivity consisted of tritium. Sr-90 was detected in all wells completed in the northern area of the upper shallow perched water zone. The maximum Sr-90 concentration detected was 516,000 ± 500 pCi/L (MW-2, December 1993) followed by 127,000 ± 500 pCi/L (MW-5, January 1995) and 98,000 ± 500 pCi/L (55-06, April 1993). The only other fission product measured in the shallow perched water was Tc-99. Tc-99 has been detected in all wells except 33-4 and MW-6. The maximum Tc-99 concentration detected in the upper shallow perched water zone was 174 ± 2 pCi/L in MW-2.

Two wells (MW-10 and -20) are completed in water-bearing zones at depths of approximately 140 ft. The maximum concentrations for tritium, Sr-90, and Tc-99 from these wells are

38,000 ± 500 pCi/L (MW-10), 25,800 ± 30 pCi/L (MW-20), and 592 ± 3 pCi/L (MW-10), respectively. A comparison of the water quality from the wells completed in the upper shallow perched water body (at approximately 110 ft) to this deeper zone indicates an increase in both tritium and Tc-99 concentrations and a decrease in the Sr-90 concentrations.

4.1.3.5 The Snake River Plain Aquifer. The SRPA underlies INTEC and is located approximately 450 ft bgs. Groundwater in the SRPA generally occurs under unconfined conditions but may be semiconfined or confined in local areas (Nace et al. 1959). Groundwater flow beneath INTEC is generally southwest and southeast at average estimated velocities of 3 m/day (10 ft/day) due to local hydraulic conditions (DOE-ID 1997a).

The structure of individual basalt flows largely governs the transmission of water through the SRPA. The upper vesicular element of a flow, with its parting, fissures, and broken basalt, combines with the fractured, often rubbly substratum of the overlying flow to form a highly transmissive interflow zone. Flow in the SRPA is generally characterized by the predominantly horizontal movement of water through hydraulically connected interflow zones. The vertical movement of water is generally limited, because it is restricted to vertical fractures and joints. The dense interior elements of basalt flows impede the vertical movement of water. Further contributing to the reduction of vertical flow is the presence of sedimentary interbeds. The transmissivity of interbeds is typically lower than the transmissivity of the basalt, but, in localized areas, interbed transmissivity may exceed that of the basalt.

Groundwater flow is affected by the local recharge, variations in hydraulic conductivity, local pumping, and possibly vertical gradients. Based on past and present water level data, groundwater flow directly beneath INTEC ranges from the southwest to the southeast, depending on the location. This local flow pattern may undergo minor changes due to the removal of the percolation ponds in 2002. However, the INTEC production wells and recharge from the sewage treatment lagoons, precipitation, and other sources will continue to influence flow patterns in the SRPA.

4.1.4 Liquid Waste/Soil Interactions

The sandy gravel used to backfill around the tank infrastructure is well drained and has a very low ability to retain water. Due to the coarse nature of the indigenous material used as backfill, liquid waste released to the sediment easily passed into the soils away from the source. Measurements of moisture content in the Big Lost River alluvial gravel (Ansley, Hull, and Burns 1988) indicated that residual moisture content ranged from 3 to 5% by weight. Using this range as the moisture content to which a spill or leak would drain, the volume of sediments that would retain a spill at residual moisture content can be calculated.

Almost all of the liquid waste released to the surficial alluvium was very acidic, with hydrogen ion concentrations ranging from 1.5 to 1.7 *M*/L (a pH equivalent of -0.176 to -0.230). The waste solution releases to the environment from the tank farm operations were usually dispersed into soil (i.e., the spill spread out) and neutralized. The hydrogen ion would compete with other cations for ion exchange sites and adsorption sites on minerals. Most minerals that might control metal or radionuclide solubility are highly soluble at acidic pH values. As the waste liquid was released to the alluvium through a spill or leak, the hydrogen ion would have initially reacted with calcite present in the alluvium (Bartholomay, Knobel, and Davis 1989). Based on the soil's ability to retain the waste and the calcite concentration in the alluvium, the amount of calcite is 10 to 20 times that needed to neutralize the acid in a release. For most spills, therefore, the "spill" is anticipated to be rapidly neutralized in the alluvium. Another ramification of the spill draining to field capacity in sandy gravel is that a significant gas phase will be present in contact with the spill. Oxygen from the atmosphere will diffuse through the pores, maintaining oxidizing conditions within the system. This rapid neutralization of tank farm waste is verifiable by the extensive previous removals and excavations of tank farm contaminated soil with no low pH areas discovered. Previous sample analysis for pH, performed in Track 2 investigations, at sites CPP-26, -27, -33, and -79 determined the pH to be above 7 and typically between 8 to 10. The pH of the perched waters has been between 7 and 8. The viscous nitric acid ooze discovered outside the tank farm at CPP-58 in 2001 was unique in that it was located in a very small pocket (less than a few feet on a side) and is suspected to be from a spill of nitric acid rather than tank farm waste. As the nitric acid reacted with minerals in the surrounding soil, one would expect that the solution would become more dense and viscous, which would retard the diffusion of the acid across the boundary where dissolution was occurring.

The clay content of the alluvium at the tank farm is low. This is likely because the entire site was excavated at various times to bedrock in order to construct the different tank farm systems. Any clay material encountered during excavation activities was likely segregated from the sand and gravel material and was not used during backfilling purposes. However, some clay fractions exist in any soil and would be present to impede the movement of some contaminants. For ion exchange reactions on clays with constant surface charge from lattice substitutions, the hydrogen ion will be the least preferentially adsorbed ion. Hydrogen ions do not compete very effectively with other cations for exchange sites. Strontium and cesium will be removed from solution primarily by ion exchange on clays, because both have relatively small hydrated ionic radii and are preferentially adsorbed onto clays relative to other ionic species in water (Deutsch 1997). Therefore, as the pH of the solution rises and ionic concentrations decrease by mixing with more dilute soil waters, strontium will exchange for other cations on clays and be removed from solution.

Soon after a spill, a low-pH halo forms around the release point in which the buffering capacity of the soil has been exhausted and soil solutions are acidic. Surrounding this halo, a zone forms in which the buffering capacity of the soil raises the pH, and radionuclides are removed from solution by ion exchange, adsorption, and precipitation. The spill will spread until the volume of the spill can be retained in the sedimentary alluvium.

Actinides, such as plutonium, will be removed from solution by formation of surface complexes on oxides of iron, manganese, and aluminum. At low pH, the surface sites are occupied by hydrogen ions, giving the surfaces a strong positive charge (Dzombak and Morel 1990). At low pH, metals will be present in solution as free cations and will have a positive charge (Pourbaix 1974). The electrostatic repulsion is stronger than the chemical affinity, which results in no adsorption on the surface. As the solution is neutralized, the hydrogen ions will be released from the surfaces of the oxide minerals, decreasing the positive charge on the mineral surface. By the time the solution pH reaches the range of 5 to 6, the surface charge has been sufficiently reduced so that chemical bonding forces become stronger than the electrical repulsion forces. Using linear free-energy relationships, Dzombak and Morel (1990) estimated that plutonium (VI, PuO_2^{+2}) will be strongly bound to iron oxyhydroxides. Therefore, by the time the solution pH has been raised to about 6, appreciable retardation capacity should be available. Laboratory experiments by Lu et al. (1998) did not detect a difference in plutonium adsorption between a pH of 6.05 and 8.44.

Waste solutions are made very acidic to retain the actinide elements in solution. Actinides form insoluble minerals with hydroxide, oxygen, carbonates, and other ligands (Pourbaix 1974). As the waste solutions are neutralized, precipitation of solid phases will also remove radionuclides, particularly actinides, from solution.

Waste solutions also were high in dissolved solids with a specific gravity near 1.2 g/cm^3. Because of this greater density, the waste solutions may tend to move downward more readily than soil water, which has a density near 1 g/cm^3. However, most of the dissolved solids consisted of sodium, chloride, and nitrate, which are very mobile in the environment. With retardation of contaminants through adsorption on sediments, the bulk of the dissolved solids contributing to the greater density would migrate ahead of the contamination. Elevated density of waste solutions will, therefore, probably not have a significant effect on migration rates of contaminants.

Waste solutions may have contained organic compounds and complexing agents. TBP, kerosene, and methyl isobutyl ketone were used in the uranium-extraction process. Some solutions were decontamination solutions, which may have contained complexing agents such as oxalate, citrate, and ethylenediaminetetraacetic acid. Complexing agents will sequester radionuclides and metals in solution and reduce the adsorption onto solid phases. Organic compounds could provide a food source for microorganisms that would consume oxygen while metabolizing the organic compounds. With sufficient organic matter present, reducing conditions could result within the area of the spill. The mobility of many metals and radionuclides is strongly dependent on the oxidation state of the element. Measurements of redox indicators in the vadose zone are required to assess the oxidation state of elements. The presence of organic compounds and complexing agents should be assessed through process knowledge and measurements.

Another process that may be of minor importance for migration of plutonium is the formation of colloidal particles in solution. Rapid increase in pH with homogeneous nucleation of plutonium hydroxide solids in solution could lead to the formation of colloidal particles. Plutonium also could adsorb onto the surface of iron, manganese, and aluminum hydroxide colloids forming during neutralization (Lu et al. 1998). These colloids would be small enough to migrate in the relatively large pores of the sand and gravel. Colloidal plutonium would be less susceptible to adsorption onto solid alluvium and could move much faster than dissolved plutonium. Studies performed on materials from the INEEL at WAG 7 indicate that only a small fraction of plutonium is transported in this fashion (Fjeld et al. 2000).

The same processes affect releases by leaks as have been discussed for releases by spills. However, some leaks that continued over an extended period may have developed a preferential flow path through the sediment and exhausted the buffer capacity along that path. In that case, the low pH halo around the release point may extend farther from the release point than for a spill. This halo may be characterized by discrete features such as fingering (which may be difficult to detect using common sampling methods such as coring). The pH of the shallow perched groundwater 400 ft south of the tank farm is 7.2 to 8.0 at a depth of 100 to 130 ft. By the time solutions reach that depth and distance, neutralization is complete. For most releases, the neutralization should be complete within the surficial sediments. For long-duration leaks, neutralization may take place farther from the source.

4.1.5 Perched Water and Contaminant Movement through the Vadose Zone in the Tank Farm Area

Processes that control the migration of contaminants through the vadose zone will significantly affect the concentration of contaminants in the SRPA. This is of particular concern for Sr-90, because the transit time of the leading edge of the dispersed plume through the vadose zone and the time required for radioactive decay to remove the Sr-90 from solution are similar. Small variations in the transit time in the vadose zone will significantly change the exposure concentration in the SRPA.

4.1.5.1 Surficial Alluvium. Water, regardless of its source, begins its gravity-driven movement through the surficial alluvium. As the water does so in contaminated soils, it displaces the waste solutions in the residual moisture content of the pores downward. Additionally, as clean infiltrate encounters contaminated sediments, the water leaches contaminants from the sediments. Precipitated minerals dissolve, resulting in concentrations that depend either on mineral solubility or on kinetic constraints. Adsorbed radionuclides are released into solution. Radionuclides held by ion exchange are readily released as solution conditions change. Radionuclides adsorbed onto oxide surfaces are not readily released (Miner, Evans, and Polzer 1982; Lu et al. 1998). The infiltrating water, therefore, becomes contaminated by dissolving solids and desorbing contaminants moving as a contaminant front. The rate at which the front moves is generally slower than the rate at which water moves. However, for conservative contaminants such as tritium or Tc-99, the rate of movement is nearly identical to that of the water. As the infiltrate moves below the spill or contaminant source, the infiltrate encounters clean sediments. Mineral precipitation reactions are not likely in this region, but ion exchange and surface complexation reactions are likely. Contaminants are removed from infiltrate by adsorption.

In the tank farm, sandy gravel extends to the basalt interface, because construction has disturbed the sediments to that depth. The 300,000-gal tank structures and the CPP-604 tank vault are built on basalt. The material removed from the excavations was stockpiled and placed back into the excavations as backfill. The backfill material was placed back directly into the excavation and did not undergo particle size sorting. The excavation and backfilling activities mixed the alluvium, which destroyed any natural layering or channeling. In other areas of the tank farm, construction activities have not excavated to basalt, and undisturbed alluvium exists between the bottom of the excavation and the basalt.

Basalt has an effective porosity of only a few percent, while the overlying alluvium typically has a porosity between 25 and 40%. The cross-sectional area available for flow decreases greatly at the basalt interface. Water flow becomes concentrated into vertical fractures and basalt flow tops. A few shallow monitoring wells installed in the alluvium to the basalt interface show that perched water rarely develops on top of the basalt. Therefore, water appears to move readily through the alluvium and into the underlying basalt by several flow processes, depending on the flux rate and hydrologic properties of the sediment and basalt. Water may flow from sediments into and through intergranular pore space in the basalt matrix (Figure 4-8, arrow 1), in closed fractures and joints with capillary permeability (Figure 4-8, arrow 2), through sediment-filled fractures (Figure 4-8, arrow 5), open fractures, or a combination of all of these features. Lateral water movement may occur in the vadose zone sediment along the sediment/basalt interface (Figure 4-8, arrow 3) or along highly permeable fractured and rubbly zones associated with basalt flow surfaces because of a contrast in hydraulic properties. Water will flow from the sedimentary materials into sediment-filled fractures or rubbly zones under unsaturated flow conditions (Figure 4-8, arrow 5). Water will not flow into or through open fractures in basalt unless near-saturated conditions occur in overlying sediments (Figure 4-8, arrow 4). Because perching does not commonly occur on alluvium/basalt interface under the tank farm, most flow into the underlying basalt is assumed to be in sediment-filled fractures and rubble zones under unsaturated conditions.

4.1.5.2 Shallow Basalt. Laboratory studies show that basalt layers do have some retardation capabilities, both from adsorption onto primary basalt minerals as well as minerals washed downward into fractures. In the cool dry climate of southern Idaho, basalt weathers slowly, with few secondary minerals forming to provide adsorption sites. Measurements of adsorption coefficients for basalt reflect this lack of sites. But it should be noted that adsorption coefficient measurements were made in the laboratory using crushed basalt samples and not on weathered basalt found on fracture surfaces.

In the quiescent periods between basalt eruptions, wind and water deposited sediment on top of the basalt flows. This sedimentary interbed material has an appreciable amount of iron oxide and hydroxide coatings on the mineral particles that will readily adsorb mobile contamination. Sedimentary material washes down into the fractures (Rightmire 1984; Rightmire and Lewis 1987), forming infill that is similar in composition to the fine-grained fractions of the sedimentary interbeds and contains clays, carbonates, and oxide minerals. Ion exchange of strontium on clays and surface complexation of plutonium would be expected primarily onto the interbeds and fracture fill material but with some contribution from primary basalt minerals. Fracture fill material would also have some buffering capacity for neutralization of acid. Therefore, while basalt has little retardation capacity, the basalt flows consist of multiple materials that could provide some retardation.

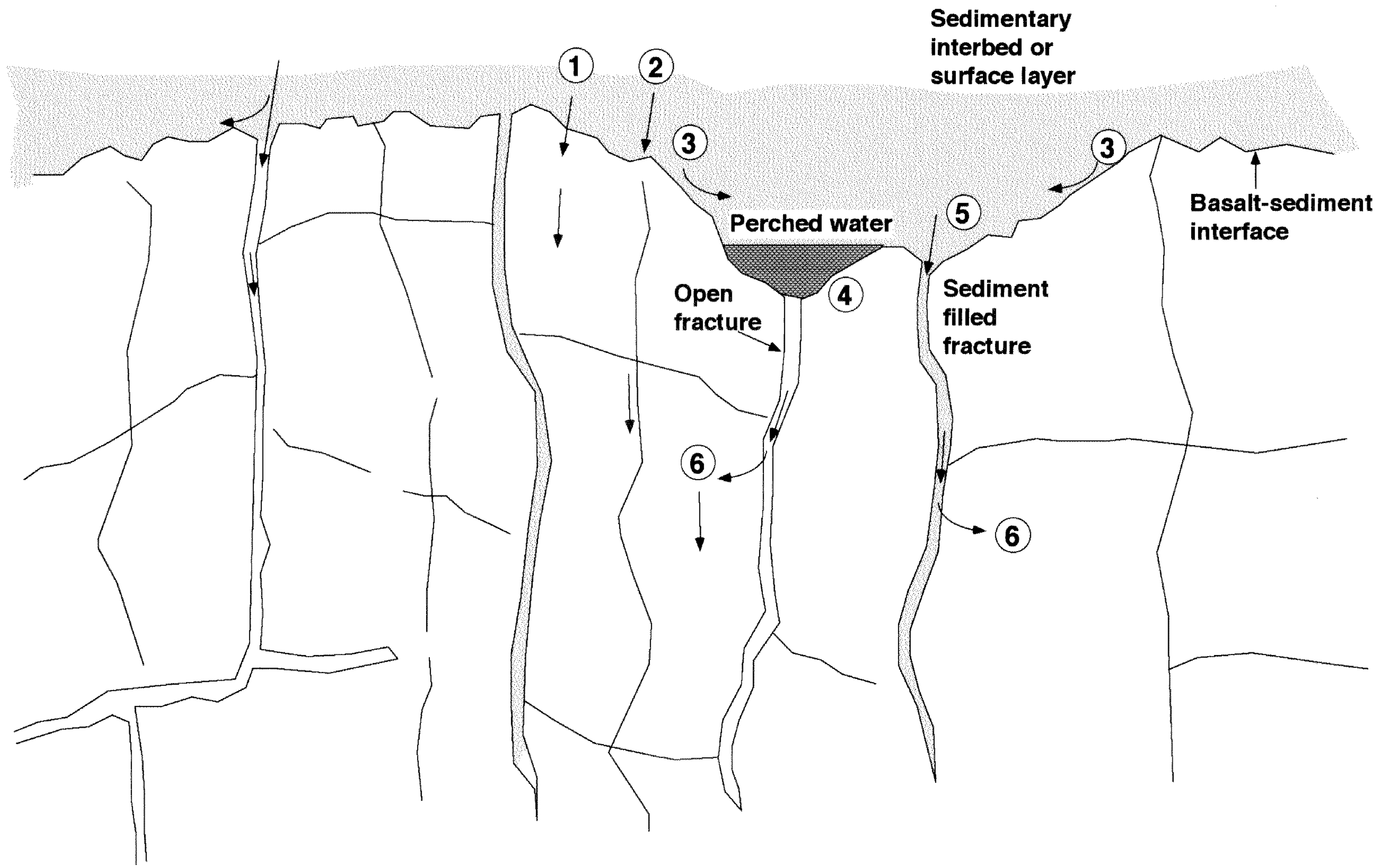

Figure 4-8. Conceptual model of pathways of water and contaminant migration at the alluvium/basalt interface.

4.1.5.3 Shallow Perched Zone. When water reaches 100 to 140 ft bgs, it encounters changing conditions, resulting in development of perched water. If enough source water is available, a well-defined mound of saturated material will occur, creating a dynamic perched water system. A reduction in the amount of recharge water available for perching results in a less dynamic perched water zone that consists of interspersed saturated and unsaturated areas that could be stagnant. The extent of saturation is based on the idea that perched water forms within and on top of sediment layers and fills in low areas in the sediment layers. Two theories are proposed as to how perched water then moves down, through, or past the perching layer. The subsurface at INTEC likely matches neither idealized conceptual model but is a combination of the two.

The first model is based on the assumption that layers of low permeability are relatively continuous and widespread. Even where thick sedimentary beds are absent, sediments deposited on the surfaces of basalt flows are assumed to be sufficient to clog the fractures, creating a low-permeability layer. Downward percolating water will accumulate on top of the layer. Accumulation will continue, resulting in a lateral spreading of the zone of saturation. Eventually, the zone of saturation will cover enough area, with sufficient hydraulic head, to drive the volume of applied water through the perching layer. In this conceptual model, perching layers are continuous, and all water moves through the perching layers.

An alternative idealized conceptual model contains perching layers that are discontinuous in the vadose zone. Layers of low permeability grade laterally into areas of high permeability. Downward percolation of water encounters a low-permeability layer, accumulates, and forms a zone of saturation. Water continues to accumulate, resulting in lateral spreading of the zone of saturation. Eventually, the zone of saturation will encounter a hole or discontinuity (area of higher vertical hydraulic conductivity) in the perching layer. As this vertical drain develops, water will flow laterally toward the drain feature. If the drain feature is a hole in the interbed material, a concentrated flow of percolation moves downward past the perching layer. Water in this case does not move through the sedimentary interbed, with its relatively high-retardation capability, but instead moves around the interbed. Because flow is concentrated in one area, rock saturation is higher and rates are faster.

Because dry wells are found in the same areas as wells with perched water and because the lateral spread of percolation pond water was determined to be less extensive than previously thought, the INTEC perching layers do not appear to be laterally continuous over an extensive enough area to form large continuous perched water bodies, making the second model discussed above the better model for the tank farm subsurface. Measured Tc-99 concentrations are higher than predicted in the SRPA, suggesting that less lateral spreading and faster downward movement of water may be occurring.

The development of shallow perched water zones results from some combination of decreased vertical permeability of the basalt and/or interbed and an increase in the volume of water available. The decrease in permeability probably is not spatially uniform, giving rise to the intermixing of wet and dry wells. This spatially nonuniform decrease in permeability may be the result of basalt surface erosional features where sediments fill depressions, creating lenses of material having low permeability that ultimately impede the vertical migration of water. Water perches on the low-permeability zones and flows downward through the more permeable zones. Between the depths of 100 and 140 ft, the basalt is interbedded with sedimentary layers. This interlayering seems to decrease the vertical permeability of the rocks in this depth range. With a decrease in permeability and development of saturated conditions, water can move laterally. Recharge from other sources at the surface could be moving laterally and contributing to a larger perched water zone. Water from multiple sources mixing in this shallow perched water zone would increase the volume of water available to carry contamination downward through the vadose zone.

The distribution of contaminants within the shallow perched water zone in the vicinity of the tank farm indicates that maximum concentrations of Tc-99, Sr-90, tritium, and nitrate lie to the south and east of the tank farm. There are, however, no monitoring wells directly under the tank farm, so the distribution of contaminants is not well defined. Existing data do not indicate whether the primary source is southeast of the tank farm or the source is the tank farm with a lateral southeast flow component in the shallow perched water zone. Low concentrations of Sr-90 to the northwest toward the Big Lost River and to the northeast toward the sewage treatment lagoons suggest that uncontaminated recharge from those two sources may contribute to the edges of the perched water zone.

In the perched zone from 100 to 140 ft bgs, water from numerous sources mixes and accumulates. The water accumulates until the head is sufficient to drive the water through or around the low-permeability zone. Infiltration from the tank farm, high in Sr-90 and nitrate from the use of nitric acid, reaches the perched water zone south and east of building CPP-604. Sr-90 concentrations in wells tapping the 110-ft interbeds (about 105 ft bgs) in that area are slightly higher than in wells tapping the 140-ft interbed (about 138 ft bgs). The pH of the shallow perched water zone is in the range of 7.2 to 7.9. If a nitric acid component is present in the recharge to this zone, it has been neutralized by the time the water reaches the existing perched water wells.

4.1.5.4 Deeper Basalt and Perched Zones. Additional basalt and interbed layers are located beneath the shallow perched water zone. A second zone of interbeds at a depth of about 246 ft does not appear to develop a significant perched water zone at the northern end of INTEC. At a depth of about 330 to 360 ft bgs, a deep perched water zone forms discontinuously on the 380-ft interbed.

Recharge moving down from the shallow perched water zone under the tank farm must move through 100 ft of basalt layers and sedimentary interbeds that were contaminated by leaks from the injection well and possibly by other past releases. The deep perched water zone contains contaminants from leaks in the INTEC injection well, direct disposal of service wastewater to well USGS-50, and any contamination moving down from overlying sources of contamination. Contamination was measured in the deep perched water zone in 1962, some 6 years before the injection well failed. Contamination remaining from the injection well and other previous releases is difficult to separate from contamination moving down from the shallow perched water zone. The deep perched water zone, tapped by wells USGS-50, MW-1-4, and MW-18-1, historically has had much less Sr-90 and much more tritium than the shallow perched water zone. Concentrations of tritium and Sr-90 in well USGS-50 have been declining slowly.

4.2 Subsurface/Groundwater Transport Modeling

Numerical models are a means of integrating all of the data available at a site. Numerical models are most useful for understanding site characterization data, hypothesis testing for long-term trends, and evaluating remedial alternatives. They are less useful for making absolute predictions of future conditions, because model predictions can be very uncertain. Models are only simplified representations of complex systems. Errors arise due to the simplification in model formulation and uncertainty in model input parameters. The errors associated with numerical models should be quantified and bounded before they are used for risk prediction or remedial design.

An appropriate use for models is designing field investigations by identifying the most useful data and locations to collect the data. Another appropriate use of numerical models is to evaluate whether the conceptual model is consistent with the data collected at a remediation site. For example, a model can determine if the SRPA potentiometric surface and hydraulic conductivity measurements are consistent with aquifer recharge underflow. Models should not be used as the only means to assess whether a COC poses a risk to human health and the environment, but they can be used as collaborating evidence along with other data.

The conceptual model will be used as the basis for developing the numerical groundwater model. The numerical model will simulate transport of water and contaminants from the tank farm soil to the aquifer and to predict future concentrations in the SRPA for use in the RI/BRA. The modeling will use field data gathered during the past OU 3-13 remedial work and planned OU 3-14 remedial work as collaborating evidence for simulated conditions in the vadose zone and aquifer.

Development of an updated INTEC conceptual and numerical model is needed, because data gathered during the OU 3-13 Group 4 remedial actions (DOE-ID 2003a) and INEEL CERCLA Disposal Facility (ICDF) groundwater investigations are inconsistent with the OU 3-13 RI/BRA conceptual and numerical models (DOE-ID 1997a). The OU 3-13 RI/BRA numerical model simplified the vadose zone by combining the 13 or more interbeds into four effective interbeds separated by fractured basalt. The interbed permeability was estimated by adjusting the value until perched water developed that matched the monitoring well observations. However, the effective interbed structure was much more continuous than the observed structure, and the model-predicted percolation pond water would spread laterally and recharge the perched water beneath the tank farm. The INTEC perched water monitoring, vadose zone tracer test, and geochemical analysis (DOE-ID 2003a) indicate this may not be occurring.

An updated INTEC groundwater model will be developed for OU 3-14. The model, which is currently being developed by OU 3-14 as part of the INTEC accelerated remedial work, is scheduled to be completed in early calendar year 2005. The INTEC model will be updated as data are gathered during ongoing OU 3-14 and OU 3-13 remedial work and will support OU 3-13 remedial activities as well.

The INTEC model will predict future SRPA contaminant distributions to be used in the OU 3-14 RI/BRA. The INTEC model will be used by OU 3-14 to simulate remedial measures and predict their ability to protect the SRPA and meet ARARs. OU 3-14 will provide the contaminant source terms, moisture flux, and K_ds to revise the INTEC model. The purpose of the INTEC model is to calculate future risks from COCs and evaluate proposed remedial actions, including impacts of flooding of the Big Lost River. The modeling approach to support the OU 3-14 RI/BRA is illustrated on the top portion of Figure 4-9. The modeling approach to incorporate other INTEC sources and support the OU 3-14 FS is also shown on Figure 4-9 and discussed in Section 4.3. The following summarizes the primary anticipated tasks of the groundwater simulations in support of the RI/BRA:

- Develop and calibrate the INTEC groundwater model – The INTEC groundwater model will be developed using OU 3-13 and 3-14 releases in the source term, including Group 2 and Group 3 sites and the former injection well, because the model will be calibrated to current contamination resulting from all historical contaminant releases. The modeling of non-OU 3-14 sites will use the same assumptions as the OU 3-13 RI/BRA, unless additional information about each site has been gathered. The calibration will use all sources of data, including physical and chemical perched water, groundwater, soil, interbed, and moisture data.

- Predict future groundwater concentrations – Once the model is calibrated, the closed WCF will be added as a potential future source term for groundwater predictions and the baseline cumulative risk evaluated. Groundwater concentrations will be predicted over time in the SRPA inside the INTEC fence. The groundwater currently does not meet drinking water standards under INTEC for several contaminants.

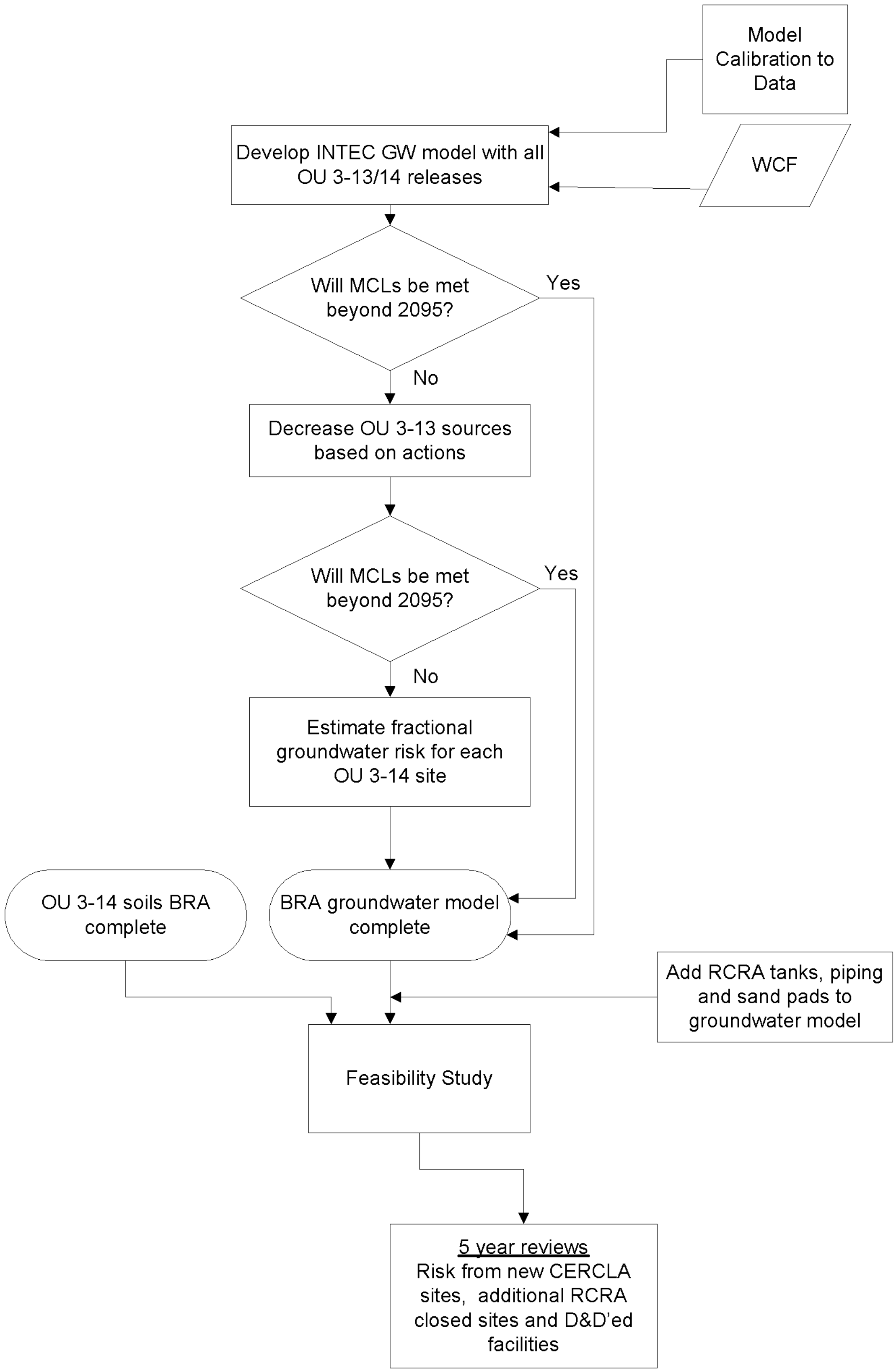

Figure 4-9. Modeling approach to support OU 3-14 RI/FS/BRA and other INTEC sources.

- Determine if MCLs will be met beyond the institutional control period – The SRPA currently exceeds MCLs for Sr-90 and Tc-99 at INTEC. If the model predicts that MCLs will be met inside the INTEC fence in the year 2095 and beyond, the BRA groundwater model will be complete. If not, the source term will be adjusted to account for any contaminant source removed or mitigated during remedial actions for OU 3-13 sites. For example, the percolation pond sediments will be removed in fiscal year (FY) 2004 and disposed in the ICDF. The model will be rerun to determine if MCLs will be met beyond the institutional control period. If MCLs will be met, the BRA groundwater model is complete. If MCLs will not be met beyond the institutional control period, the fractional groundwater risk for each OU 3-14 site will be determined. This information will be necessary during remedy evaluation to determine if the soil remedy will also be required to be protective of groundwater for each tank farm soil site.

4.3 Modeling of Other Sources

Regardless of whether the INTEC groundwater model predicts that MCLs will be met in the SRPA in the future, a feasibility study will be prepared because the risk of external exposure from tank farm soils is currently unacceptable and will be unacceptable beyond the institutional control period. Once the fractional groundwater risk for each site is determined or if MCLs are predicted to be met beyond the institutional control period, the RCRA tank farm sources will be added to the INTEC groundwater model to determine the combined effect of CERCLA and RCRA sources for use in the feasibility study (see Figure 4-9). In the FS, the model will be used to ensure that the remedies for tank farm soils, in combination with assumed residual contamination from the RCRA tank farm sources, will be protective of the Snake River Plain Aquifer. In addition, the remedies being evaluated for tank farm soil have to be compatible with the remedies assumed for the RCRA systems in the tank farm. If other INTEC facilities are closed before the FS is complete, they will be added to the groundwater model to ensure that the FS remedies, in combination with closed facilities, will be protective of groundwater. The residual inventory for tank farm tanks, RCRA piping, and sand pads; release mechanisms; and timing of the releases will be based on information acquired during tank farm cleaning and closure. Because these tank farm systems may not be closed by the time the OU 3-14 FS is prepared, assumptions will have to be made regarding their likely end state.

Other INTEC facilities will eventually be closed, but their end states will not be determined when the OU 3-14 FS is prepared. Screening models may be developed for use in quickly calculating the cumulative risk or dose from all of the facilities at the INTEC. These models would be designed to complement and be integrated with the OU 3-14 model. The OU 3-14 model will contain a detailed and complex numerical model of vadose zone flow and transport for CERCLA sites at the INTEC. The screening models would use a much simpler numerical analysis that does not simulate all of the subsurface detail evaluated in the OU 3-14 model. However, these screening models would be calibrated to the OU 3-14 model results so that the two models provide essentially the same results for typical INTEC risk assessment problems. Agency approval of these screening models, if used, will be obtained during development of the FS.

During 5-year reviews for OU 3-14, new CERCLA sites can be added to the INTEC groundwater model, along with source terms from additional RCRA-closed facilities and facilities for which DD&D has been completed. Using screening models in combination with the INTEC groundwater model would ensure protection of the Snake River Plain Aquifer from all the INTEC facilities that have been closed during the previous 5-year period and a best estimate of the source term for facilities that are not yet in their final end state.